X-732-73-256

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NASA TM X-70465

SUMMARY OF ATTITUDE DYNAMIC ANALYSIS FOR IMP-J WIRE ANTENNA SPACECRAFT

(NASA-TM-X-70465) SUMMARY OF ATTITUDE DYNAMIC ANALYSIS FOR IMP-J WIRE ANTENNA SPACECRAFT (NASA) 26 p HC $3.50 CSCL 22C

N73-31764

Unclas

G3/31 13779

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SEPTEMBER 1973

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

X-732-73-256

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Greenbelt, Maryland

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SUMMARY OF ATTITUDE DYNAMIC ANALYSIS
FOR IMP-J WIRE ANTENNA SPACECRAFT

L. W. Bell

1. INTRODUCTION

The mission objective of the IMP-J S/C is to perform detailed and near-continuous studies of the interplanetary environment for orbital periods comparable to several rotations of active solar regions. Launch is expected in the fourth quarter of 1973. This report summarizes the work done in the following attitude dynamic areas:

1. Determination of acceptable deployment sequences.
2. Simulation of EFM antenna deployment 0-200 feet (nominal and failure modes).
3. Contingency analysis.

2. SPACECRAFT DESCRIPTION

The IMP-J S/C weighs approximately 876 lbs. Key dynamic elements are: Freon gas thrusters for spin axis precession and spin rate control, liquid ring nutation damper, liquid ring antenna motion damper, and four EFM antenna dispenser mechanisms.

Figure 1 shows a sketch of the S/C when the EFM antennas are fully deployed to 200 feet. The first 150 feet of antenna, measured from the hub, consists of 305 stainless steel wire, linear density of 0.42 gms/ft, insulated with a coating of FEP, black teflon, linear density of 0.18 gms/ft. The remaining 50 feet of antenna is bare wire.

3. MISSION PROFILE

The IMP-J S/C will be launched from the Eastern Test Range (ETR) into an elliptical transfer-orbit. A kick motor will be fired at apogee to place the S/C in a high near-circular earth orbit. During the first circular mission orbit and following the despin of the S/C to 18 rpm for deployment of the experiment and attitude control system (ACS) booms, the S/C spin axis will be placed normal to

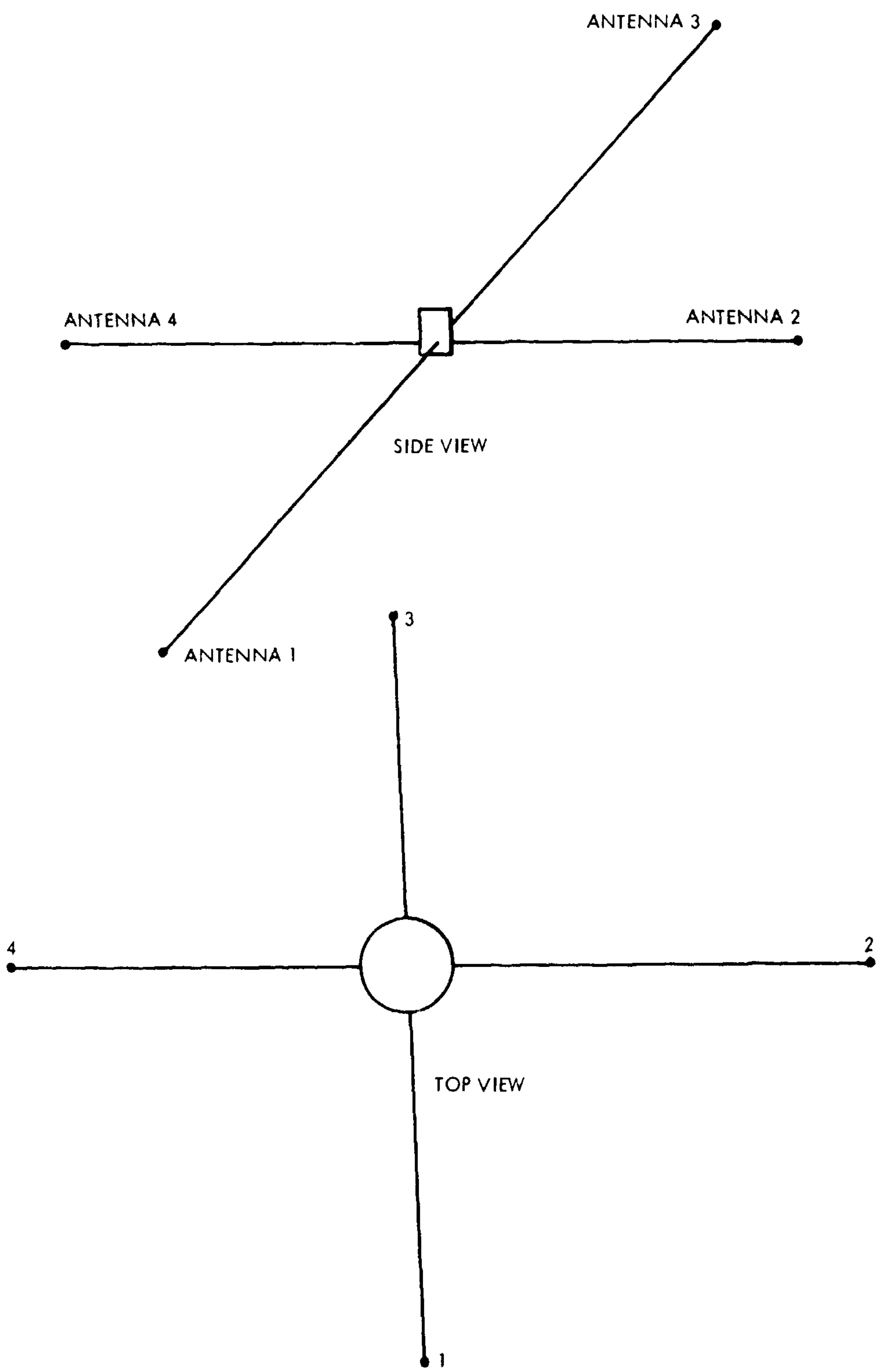


Figure 1. Two views of the IMP-J S/C with only the EFM antennas deployed

the ecliptic plane and the spin rate increased to 23 rpm. The EFM antenna deployment will be accomplished, after the S/C is spun up to 65 rpm, by deploying the antennas alternately in pairs (i.e., antennas 1 and 3 and antennas 2 and 4) see Figure 1. The antennas are deployed at a rate of 0.14 feet/second.

4. DEPLOYMENT SEQUENCES

Due to the limited amount of on board power available at time of deployment, approximately 85 watts, and the amount of power required by each antenna mechanism to deploy an antenna, approximately 29 watts, the EFM antennas are constrained to be deployed in alternate pairs. In addition to the above constraints, the following constraints were imposed to prevent placing the antennas under an excessive tension load and/or to conserve the use of the ACS.

(a) No antenna is to be under more than 10 lbs of tension during and after deployment.

(b) The spin rate at the start of deployment cannot exceed 100 rpm.

(c) There cannot be more than three spinup periods during antenna deployment.

(d) The S/C cannot be spun up more than 20 rpm during any spinup period or cause the spin rate to exceed the spin rate of the S/C at the start of deployment.

(e) All EFM antennas must be of equal length during any spinup of the S/C.

(f) The S/C spin rate cannot be less than 23 rpm during and after deployment of the EFM antennas.

A computer program was designed to select all possible deployment sequences that could meet the above constraints. The program simulated the deployment of the EFM antennas in alternating pairs for incremental deployment lengths of 20 feet, 25 feet and 40 feet. The results of the three simulations are tabulated in Tables 1-3.

A careful study of Tables 1-3 leads to the recommendation that the following deployment sequence be considered as the primary EFM antenna deployment configuration for the IMP-J S/C:

Table I
Possible Deployment Schemes for Deploying the IMP-J Wire Antenna in Alternating Pairs in 20 Ft Increments to a Length of 200 Ft

Initial Spin Rate (rpm)	Maximum Tension (lbs)	Spin-Up Number	Spin-Up Increment (rpm)	Antenna Length at Spin-Up (ft)
85	8.43	1	6.73	160
80	8.23	1	8.52	160
75	6.56	1	2.42	160
		2	6.19	180
70	8.23	1	12.10	160
70	6.41	1	4.21	160
		2	6.19	180
65	8.23	1	13.89	160
65	6.41	1	6.00	140
		2	6.19	160
60	6.41	1	1.92	140
		2	6.28	160
		3	6.19	180
55	8.23	1	4.19	140
		2	14.17	160
55	6.41	1	4.19	140
		2	6.28	160
		3	6.19	180

Table II
Possible Deployment Schemes for Deploying the IMP-J Wire Antennas in Alternating Pairs in 25 Ft Increments to a Length of 200 Ft

Initial Spin Rate (rpm)	Maximum Tension (lbs)	Spin-Up Number	Spin-Up Increment (rpm)	Antenna Length at Spin-Up (ft)
80	7.64	1	7.10	175
75	6.84	1	0.80	150
		2	8.00	175
70	6.84	1	2.82	150
		2	8.00	175
65	6.84	1	4.84	150
		2	8.00	175
60	9.21	1	17.68	150
60	6.84	1	6.86	150
		2	8.00	175
55	6.84	1	1.06	125
		2	8.08	150
		3	8.00	175
50	6.84	1	3.75	125
		2	8.08	150
		3	8.00	175
45	9.21	1	6.44	125
		2	18.90	150
45	6.84	1	6.44	125
		2	8.08	150
		3	8.00	175
35	9.21	1	5.34	100
		2	7.66	125
		3	18.90	150

Table III

Possible Deployment Schemes for Deploying the IMP-J Wire Antenna in Alternating Pairs in 40 Ft Increments to a Length of 200 Ft

Initial Spin Rate (rpm)	Maximum Tension (lbs)	Spin-Up Number	Spin-Up Increment (rpm)	Antenna Length at Spin-Up (ft)
85	9.65	1	6.73	160
80	8.55	1	8.52	160
75	8.23	1	10.31	160
70	8.23	1	12.11	160
65	8.23	1	13.89	160
60	8.23	1	2.40	120
		2	14.17	160
55	8.23	1	5.24	120
		2	14.17	160
50	8.23	1	8.08	120
		2	14.17	160
45	8.23	1	10.92	120
		2	14.17	160
40	8.23	1	0.39	80
		2	13.48	120
		3	14.17	160
30	8.23	1	8.49	80
		2	13.48	120
		3	14.17	160

Primary EFM Antenna Deployment and Spin-Up Schedule	
First spin-up to	65 rpm
First deployment to 160 feet in 40 foot increments	23 rpm
Second spin-up to	37 rpm
Final deployment to 200 feet in 40 foot increments	23 rpm

A further study of Tables 1-3 leads to the recommendation that the following deployment sequence be considered as the alternate EFM antenna deployment configuration for the IMP-J S/C:

Alternate EFM Antenna Deployment and Spin-Up Schedule	
First spin-up to	65 rpm
First deployment to 160 feet in 20 foot increments	23 rpm
Second spin-up to	37 rpm
Final deployment to 200 feet in 20 foot increments	23 rpm

The top graph in Figure 2 is a plot of the tension load on each of the antennas during nominal deployment of the EFM antennas. The lower graph is a plot of the S/C M.O.I. about the spin axis and the S/C spin rate during the deployment.

5. SIMULATION OF NOMINAL EFM DEPLOYMENT

A nominal deployment of the IMP-J S/C wire antennas was simulated using the Flexible Body Program. The antennas were deployed according to the primary deployment configuration using the first mode shape for a string. All discussions on tip deflections refer to in-plane deflections unless otherwise specified. Figure 3 is a plot of the antenna tip deflection as a function of time for the deployment of the antennas from 160 feet to 200 feet and a 300 second coast phase after the S/C achieved full deployment. Prior to the plotted deflections, the S/C had been spun up from 23 rpm to 37 rpm. During the coast phase, the S/C spin rate is 23 rpm. The maximum deflection encountered during the antenna deployment was -19 feet for antennas 2 and 4. The maximum deflection occurred during the deployment of antennas 2 and 4 with antennas 1 and 3 fixed at 200 feet. After the

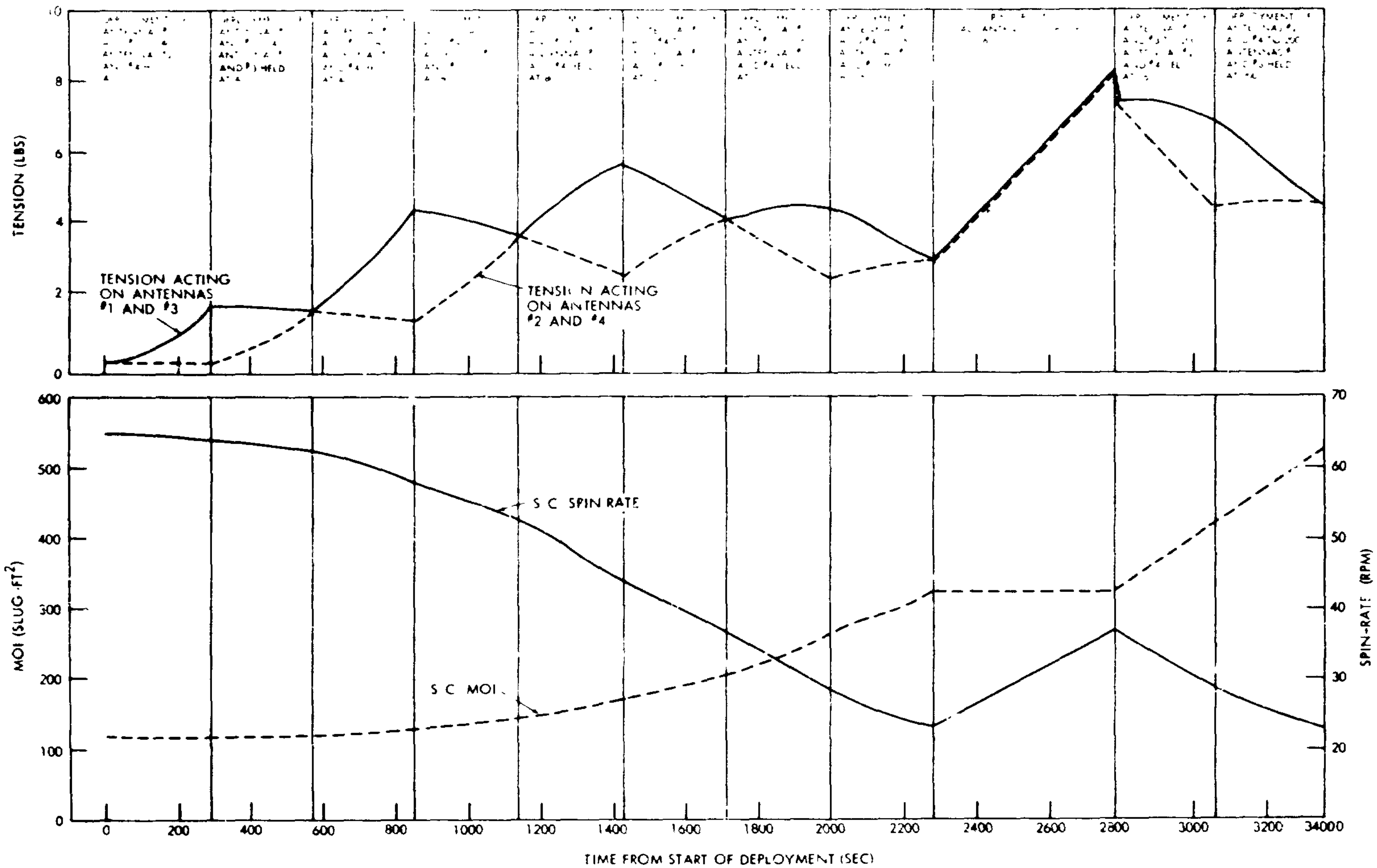


Figure 2. Tension Profile of IMP-J S/C antennas during nominal deployment of EFM antennas. Profiles of S/C M.O.I. about spin axis and spin rate during nominal deployment of EFM antennas.

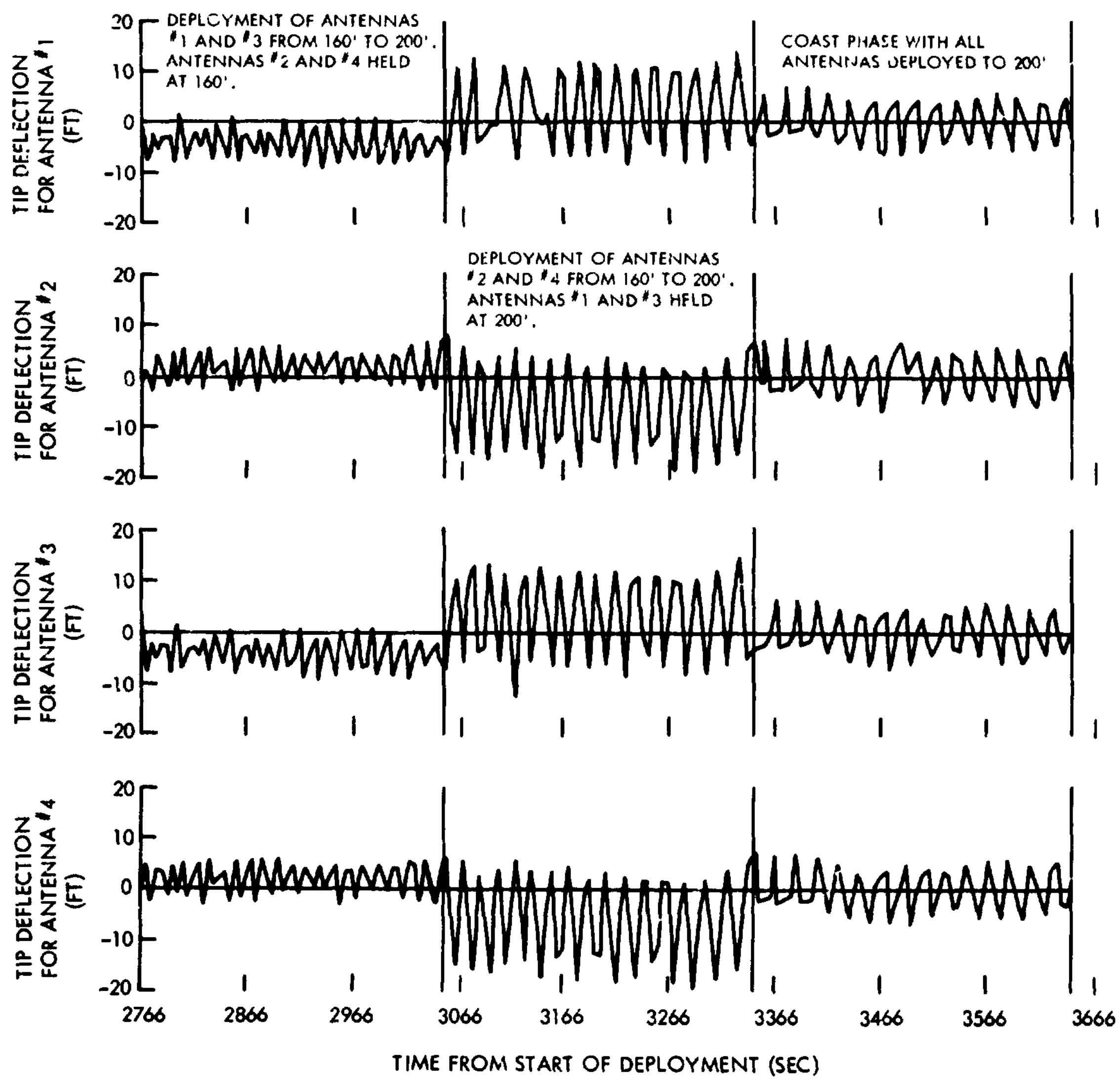


Figure 3. Time History of Nominal Deployment of IMP-J wire antennas from deployment length of 160 ft to 200 ft and coast phase.

S/C achieved full deployment, the maximum tip deflection is ±7 feet and the maximum deflection angle is ±2°. This deflection will be minimized by the on board antenna motion damper. The tension profile is the same as in Figure 2.

6. SIMULATION OF EFM DEPLOYMENT FAILURE

In the course of deploying the EFM antennas, it is possible that one or more of the antennas would fail. Two failure cases were simulated using the Flexible Body Program.

Case 1: Antennas 1, 2 and 3 were allowed to deploy nominally while antenna 4 was not allowed to deploy. Antennas 1 and 3 were deployed alternately with antenna 2 according to the primary deployment configuration. However, the S/C spin-up, which occurs when the antennas reach a length 160 feet, will be to a spin rate of 35 rpm. The maximum antenna deflection, during the deployment, is -20 feet. Figure 4 is a plot of the antenna deflections during the coast phase, after the three antennas have been fully deployed to 200 feet. The figure illustrates that antennas 1 and 3 are oscillating about an equilibrium position other than that for the nominal deployment case; however, antenna 2 is oscillating about the nominal equilibrium position. The S/C spin axis is rotated by 0.25° with respect to the preferred inertial orientation of the spin axis. Figure 5 illustrates the antenna and S/C orientation. This new orientation is a result of a shift in the principal axis with respect to the body fixed coordinates. The maximum deflection of the antennas is ±10 feet and the maximum angle of deflection is ±2.9°. The spin rate of the S/C during the coast phase is 23 rpm.

Case 2: Antennas 1 and 3 were allowed to deploy nominally while antennas 2 and 4 were not allowed to deploy. Antennas 1 and 3 were deployed simultaneously and continuously from 0-200 feet; however, no spin-up was necessary during this deployment.

Figure 6 is a plot of the tip deflections during the antenna deployment and the coast phase. The S/C spin rate during the coast phase is 23.5 rpm. The maximum antenna deflection is ±4.75 feet and the maximum angle of deflection is ±1.36°. The peak tension on either antenna during deployment is 6.8 lbs.

7. UNEQUAL EFM DEPLOYMENT RATES

The deployment of the EFM antennas at unequal deployment rates was simulated with the Flexible Body Program. Antennas 1 and 2 were deployed at the

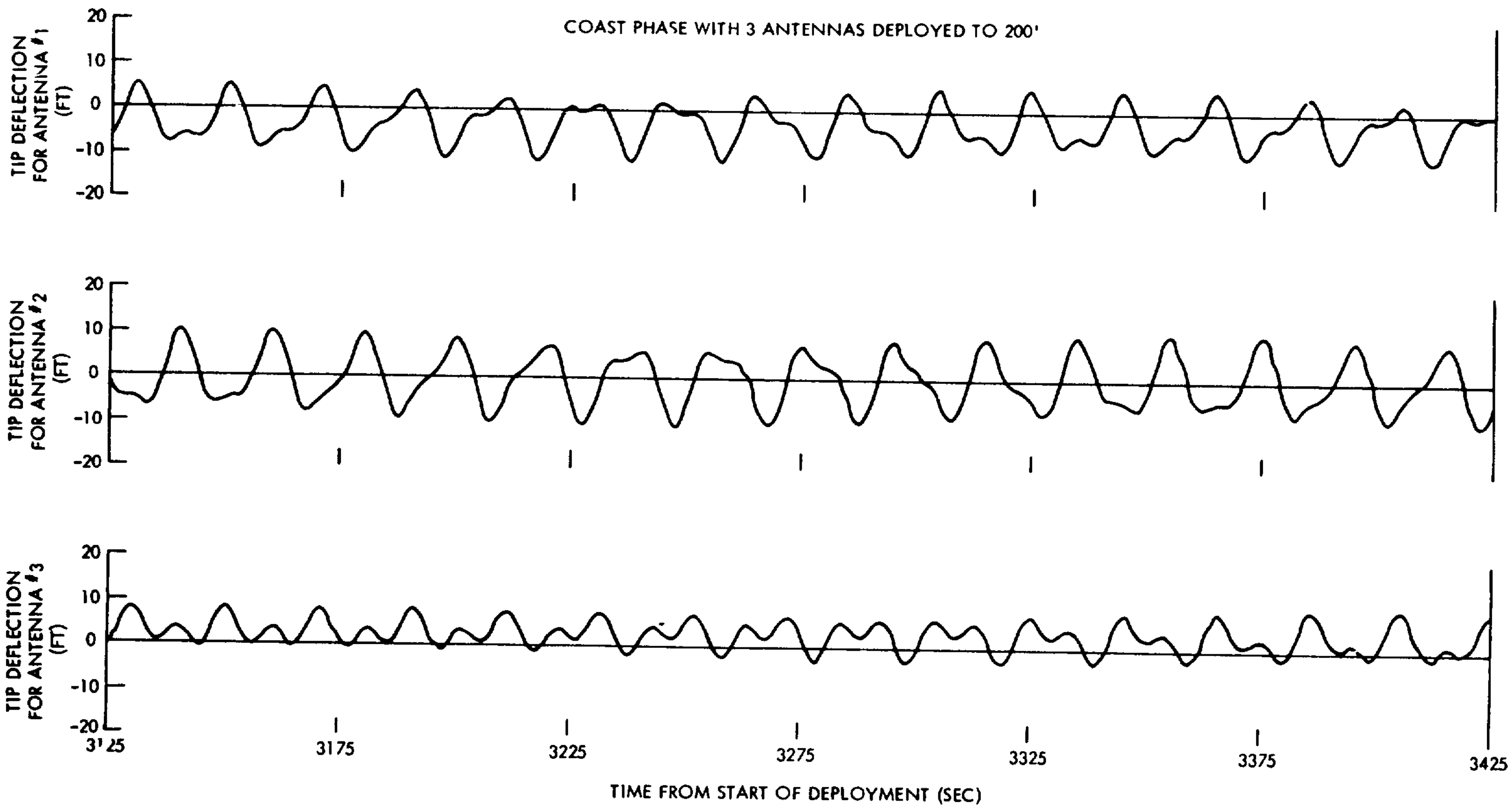


Figure 4. Time History of the IMP-J wire antennas during coast phase, only three of the four antennas were deployed simultaneously. Antenna #2 was deployed alternately with antennas #1 and #3.

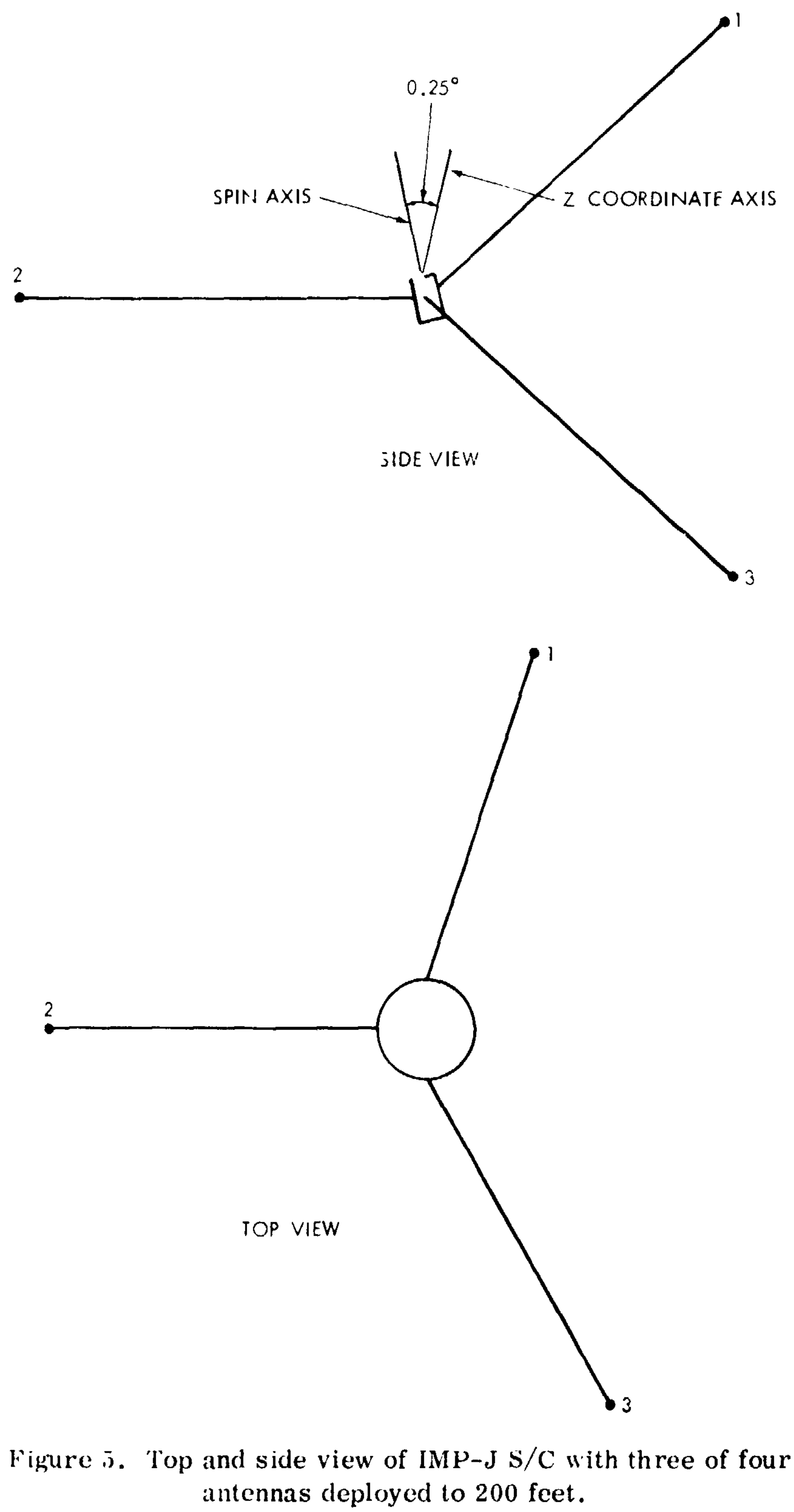


Figure 5. Top and side view of IMP-J S/C with three of four antennas deployed to 200 feet.

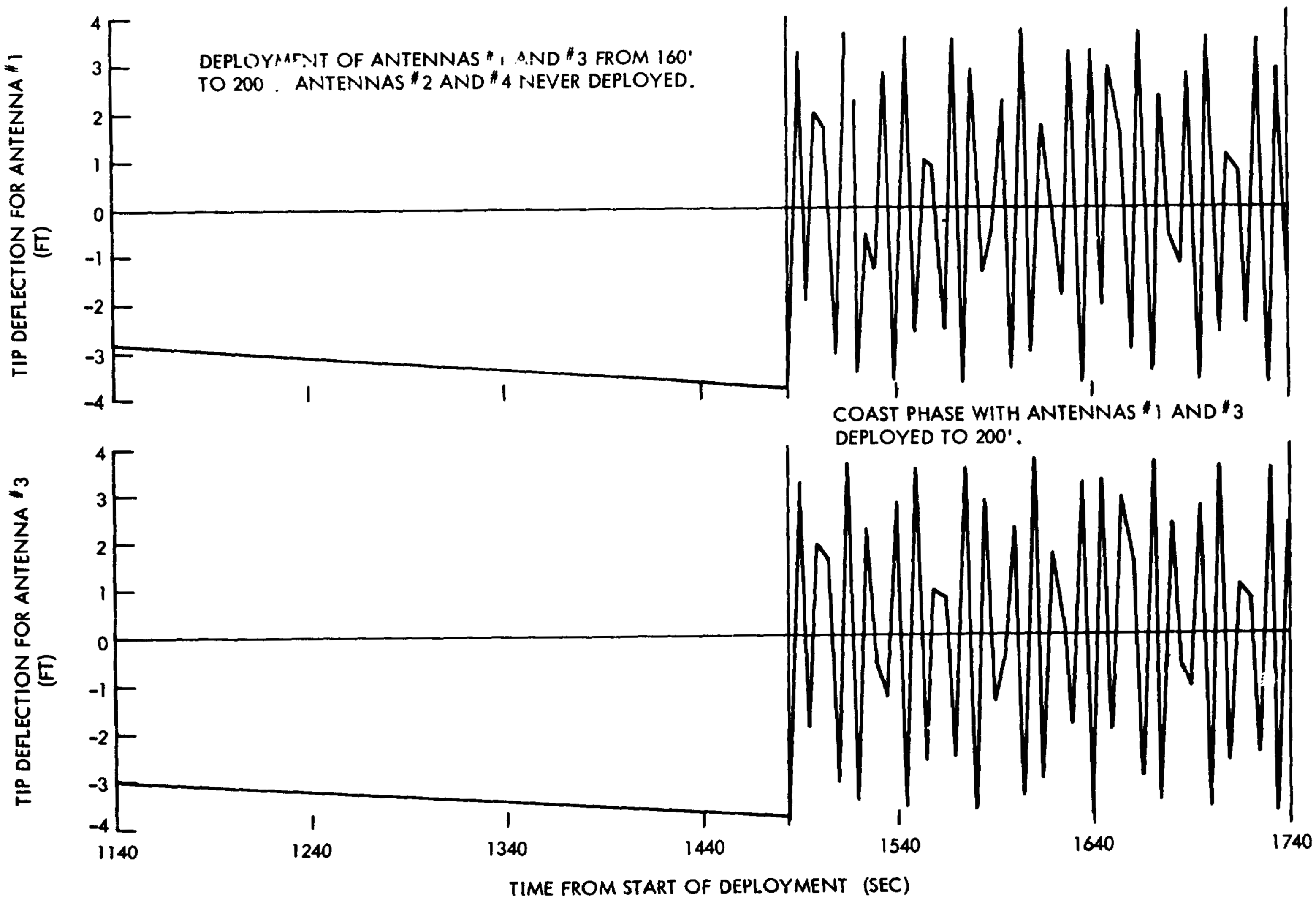


Figure 6. Time history of deployment of antennas #1 and #3 from 160 ft to 200 ft and coast phase Antennas "2 and #4 never deployed.

nominal rate of 0.14 ft/sec, where as, antennas 3 and 4 were deployed at a rate of 20% less than the nominal rate, i.e., 0.112 ft/sec. Figure 7 is a plot of the tip deflections during the deployment of the antennas from 160-200 feet and the coast phase after the antennas have been fully deployed. Prior to this plot, the S/C has been spun up from 23 rpm to 37 rpm. The maximum deflection during the deployment is ±12 feet for antennas 2 and 4 with antennas 1 and 3 held at 200 feet. After the antennas are fully deployed, the maximum tip deflection is ±9 feet and the maximum angle of deflection is ±2.57°. Antenna 3 had to be trimmed after antenna 1 had been deployed the specified deployment increment, and similarly, antenna 4 had to be trimmed after antenna 2 had been deployed to the specified deployment increment.

8. ANTENNA DISPENSER MISALIGNMENT

A simulation of the EFM antenna behavior, with the antenna dispenser mechanisms misaligned, was made with the Flexible Body Program. The following two cases where simulated.

Case 1: The antenna dispenser mechanisms for antennas 1 and 2 where assumed to be located in the nominal position; however, the dispenser mechanisms for antennas 3 and 4 where displaced six inches higher along the z axis but with the nominal x-y position. Figure 8 is a plot of the tip deflections during the coast phase, after all the antennas had been deployed to 200 feet. The maximum deflection during deployment and the deflection of the tip after achieving full deployment was found to be the same as that for nominal deployment.

Case 2: The antenna dispenser mechanisms for all the antennas were displaced three inches from these nominal positions in the x-y plane but all retained the same z coordinate. Figure 9 is a plot of the tip deflections during the coast phase. The maximum deflection during and after EFM antenna deployment was the same as that for the nominal deployment.

9. ANTENNA BREAK AWAY

A study was undertaken to gain insight into the behavior of the S/C if one of the antennas should break away. It was assumed that all of the EFM antennas deployed nominally to 200 feet and at sometime later, one of the antennas broke away at the point of attachment, see Figure 10. If the distance from the S/C center of the hub to the antenna break point is less than 200 feet, and the angle that the trailing antenna makes with the x-axis of an inertia coordinate system, with coordinate origin at the center S/C hub, is greater than that of the break

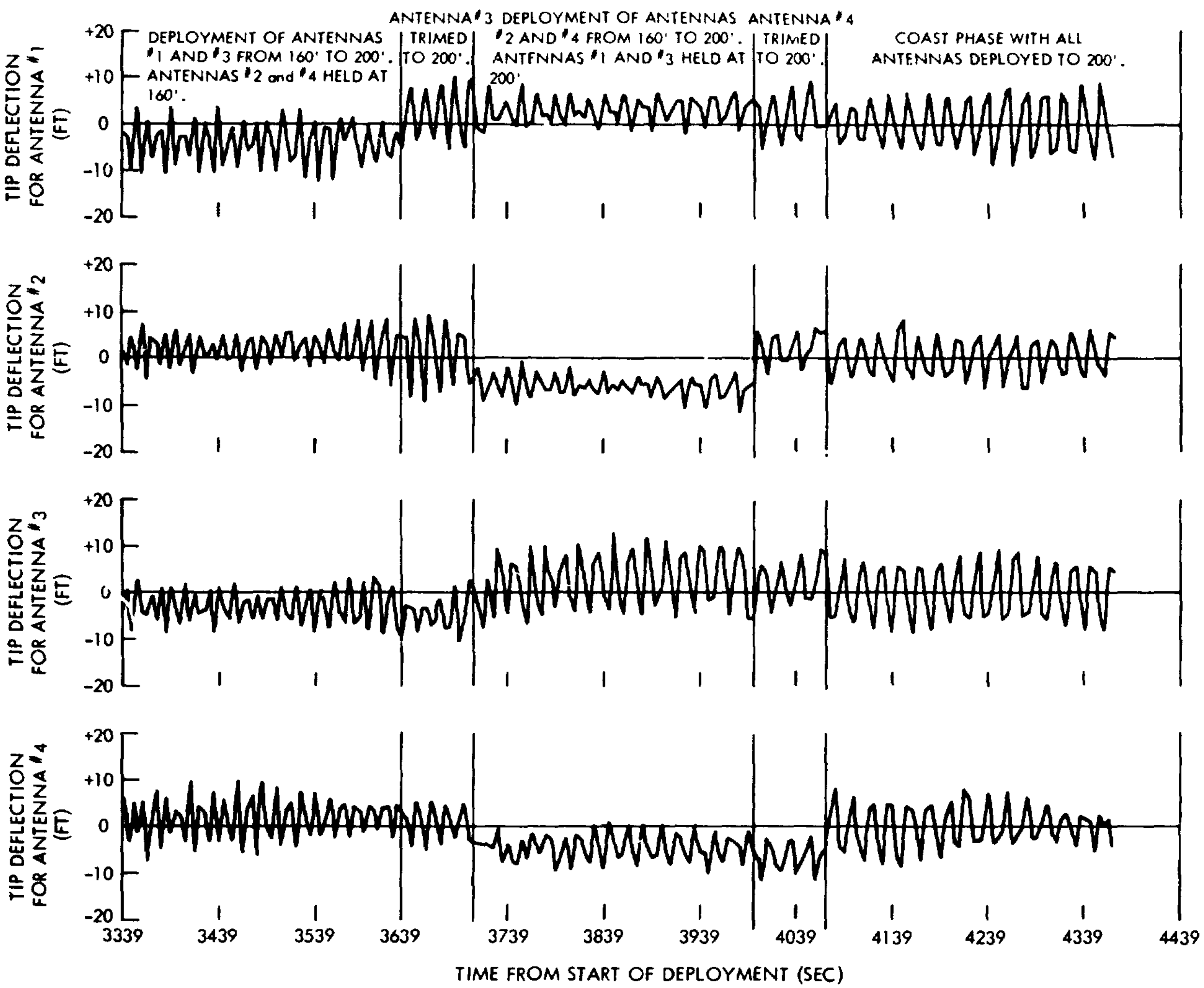


Figure 7. Time history of the deployment of the IMP-J wire antennas from deployment length of 160 ft to 200 ft and coast phase. The rate of deployment for antennas #3 and #4 is 20% lower than that for antennas #1 and #2.

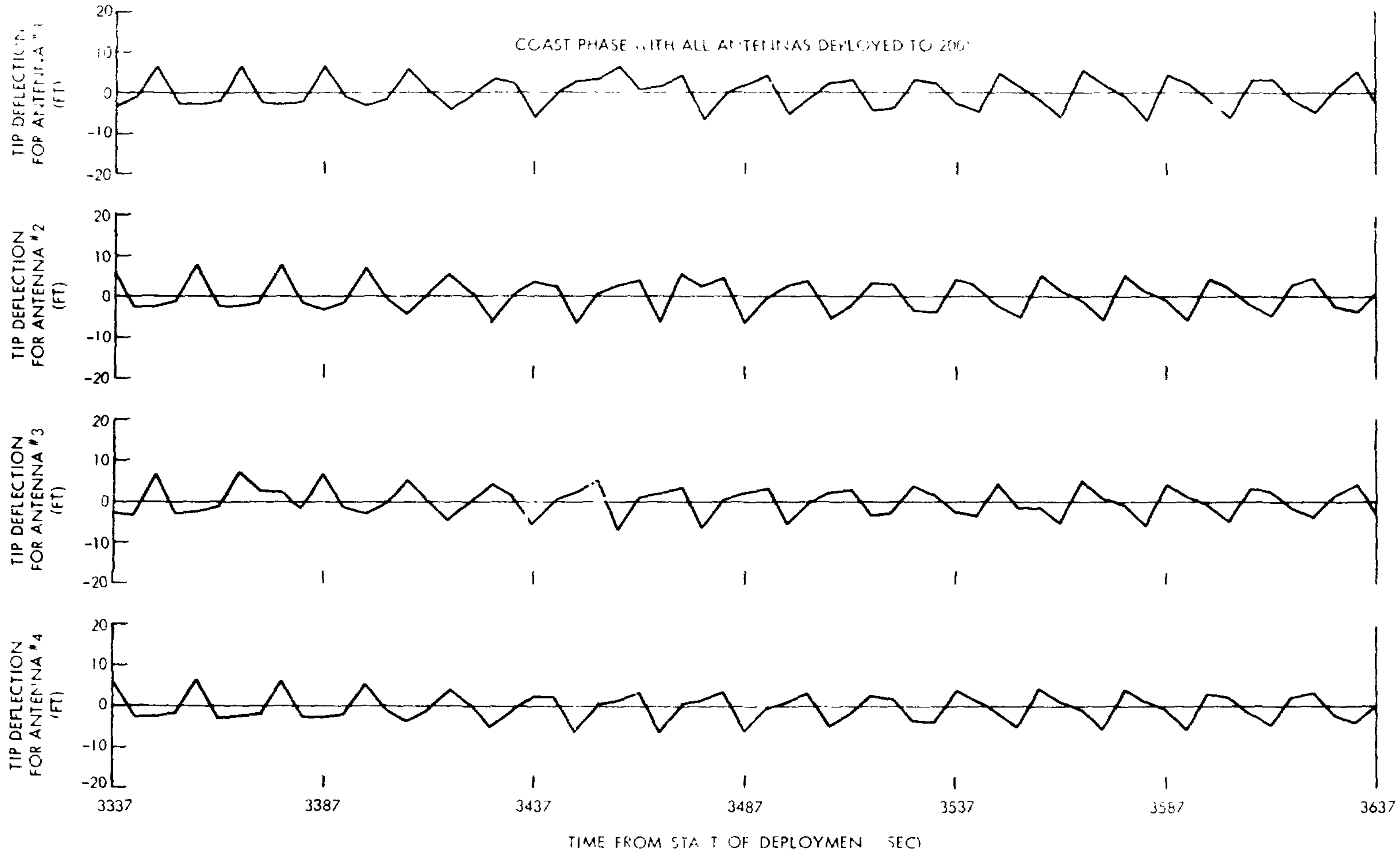


Figure 8. Time histo.y of IMP-J wire antennas during coast phase when all the antennas are deployed to 200 ft. The dispenser mechanisms for antennas #3 and #4 are displaced +6 inches along the Z-axis from those for antennas #1 and #2.

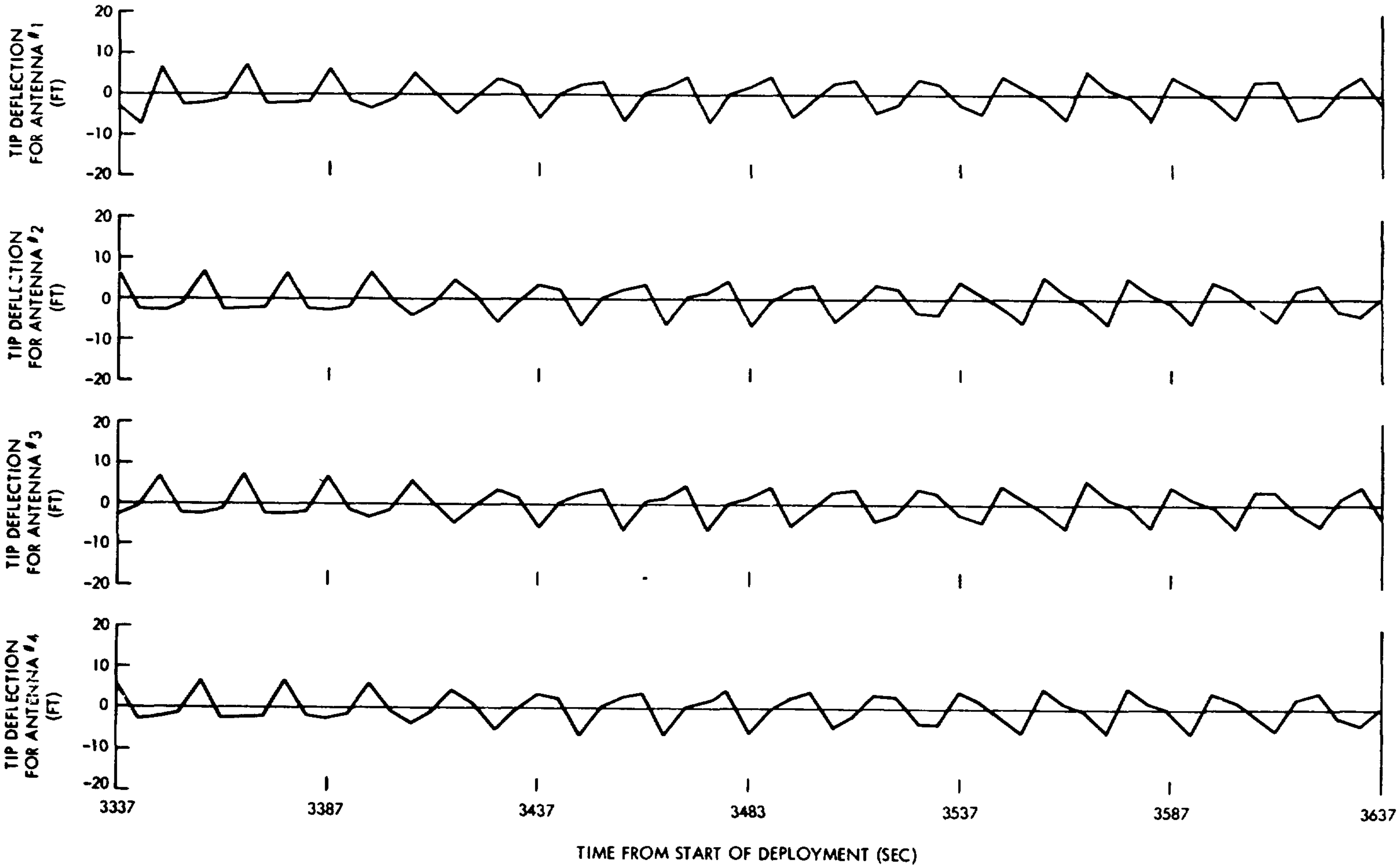
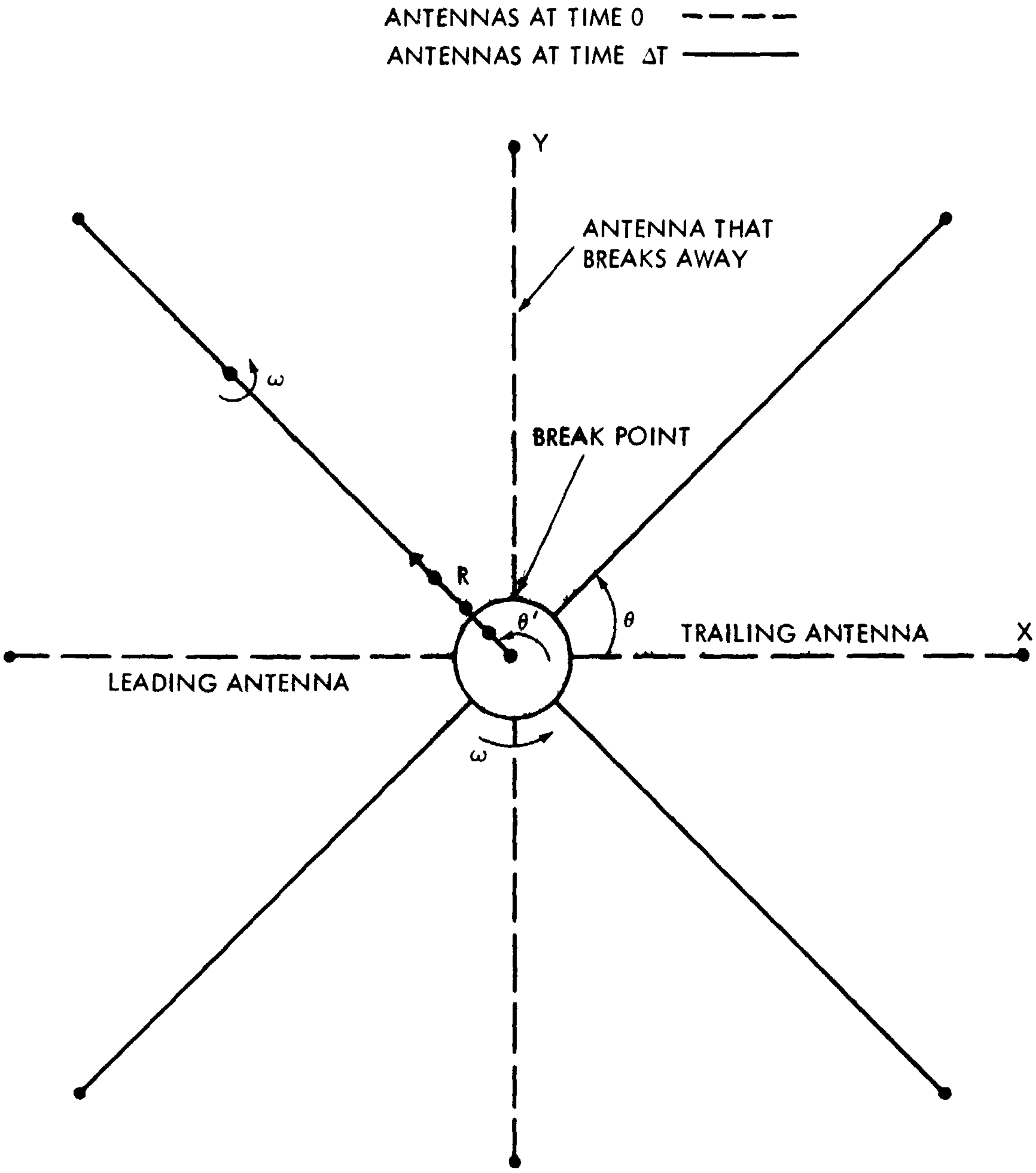


Figure 9. Time history of IMP-J wire antennas during coast phase when all the antennas are deployed to 200 ft. All the dispenser mechanisms were displaced by 3 inches from their nominal position in the X-Y plane.



R - DISTANCE OF ANTENNA ROOT FROM S/C SPIN AXIS.

θ - ANGLE OF TRAILING ANTENNA RELATIVE TO INERTIA X AXIS AT TIME ΔT

θ' - ANGLE OF RADIUS VECTOR TO BREAK POINT RELATIVE TO INERTIA X AXIS AT TIME ΔT

ω - S/C SPIN RATE

Figure 10. Antenna Break Away

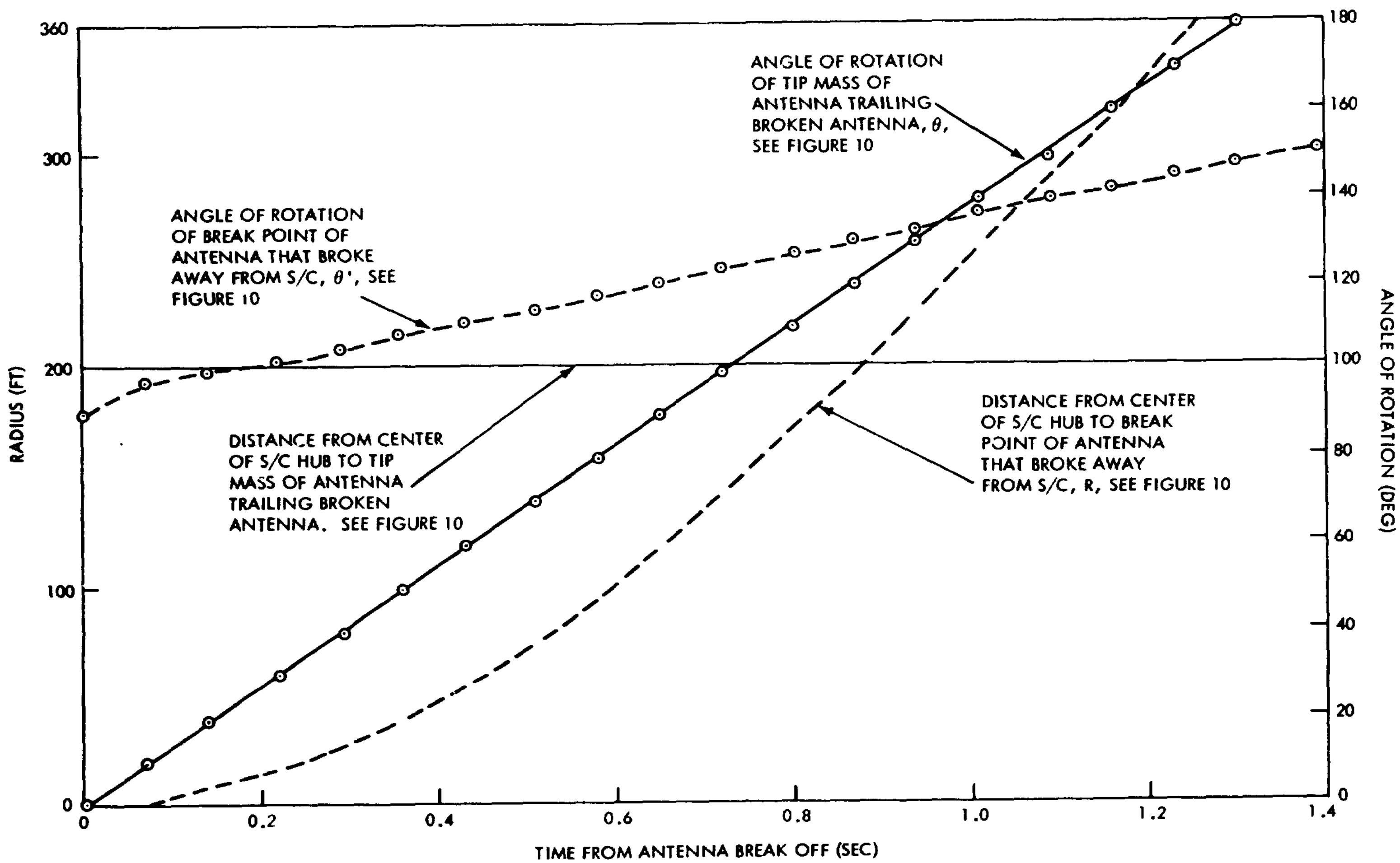


Figure 11. Plot of θ, θ' and R, see Figure 10.

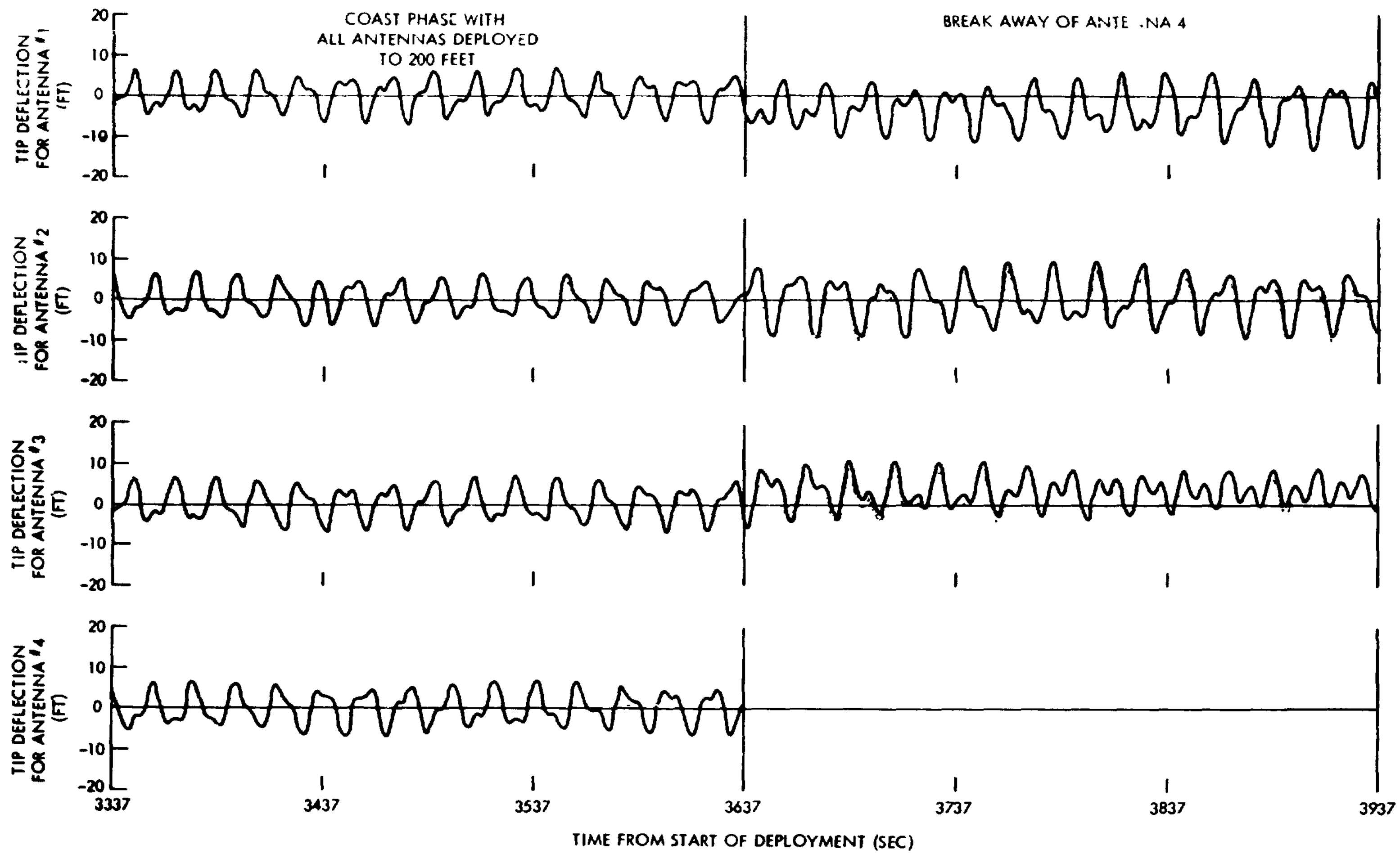


Figure 12. Time history of EFM antenna tip deflections prior to and after antenna #4 br· ks away from S/C hub.

point, the antennas will probably make contact. Figure 11 is a plot of θ, θ' and R. This figure illustrates that the antenna which broke away from the S/C will not make contact with the trailing antenna. A similar analysis showed that the broken antenna will not make contact with the leading antenna either. Figure 12 is a plot of the antenna tip deflections before and after antenna 4 was assumed to break away from the S/C hub. A comparison between Figure 4 and the last 300 seconds of Figure 12 indicate that the S/C will behave as if only three of the four antennas deployed, and will have an orientation similar to that shown in Figure 5.

10. ACKNOWLEDGMENTS

The author is appreciative for the assistance given by Dr. [illegible] Longman and Mr. S. Hilinski. Dr. Longman gave many helpful suggestions in discussions on antenna break away failure; Mr. Hilinski assisted in the plotting of several graphs.

11. REFERENCES

1. L. Heald, J. E. Cresswell, and E. C. Trott, "A Galactic Noise Radiometer for the UK-2/S-52 Satellite," Memorandum No. SLM 610 (June 1963), Applied Electronics Laboratories, The General Electric Company Ltd. Stanmore, Middlesex, England, p. 4.

2. "EFME Antenna," Contract NAS5-11822, Mid-Program Progress Report, 746-403-P17-2, May 1971, Fairchild Industries Inc., Fairchild Space and Electronics Division.